National Park Service
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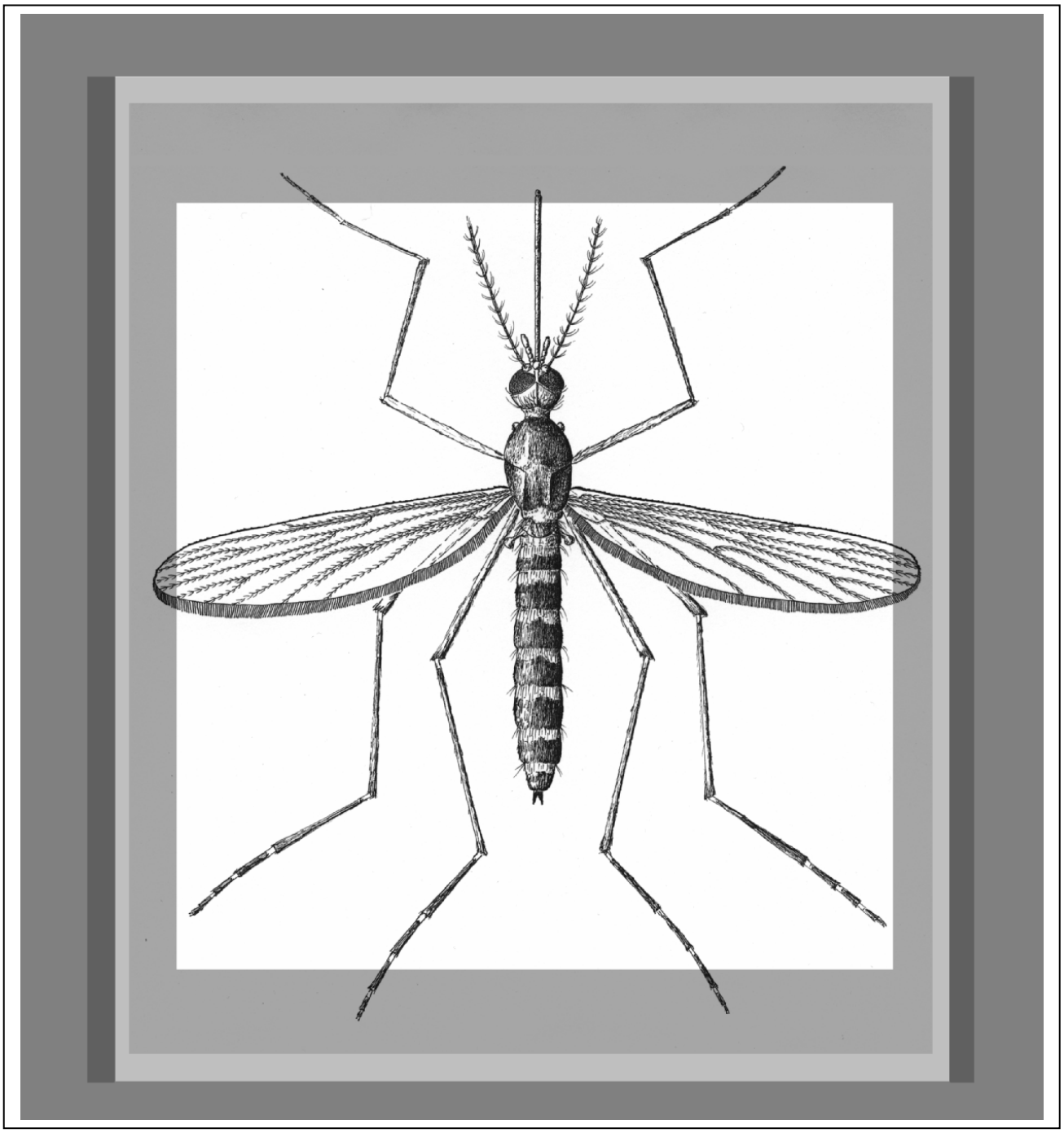
Northeast Region
Boston, Massachusetts

# Distribution of Mosquitoes in National Park Units of the Northeastern United States

Technical Report NPS/NER/NRTR--2006/050



**ON THE COVER**
*Aedes vexans*, a common species and potential arbovirus vector.
Illustration by: Antonia L. Ross

# Distribution of Mosquitoes in National Park Units of the Northeastern United States

**Technical Report NPS/NER/NRTR--2006/050**

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U.S. Department of the Interior
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## EXECUTIVE SUMMARY

Mosquito species commonly involved in West Nile Virus (WNV) transmission in eastern North America include *Culex pipiens, Cx. restuans, Cx. salinarius,* and *Aedes vexans*. We surveyed mosquitoes at eight national park sites in the northeastern U.S., and developed surveillance recommendations based on a comparison of catches in $CO_2$-baited CDC miniature light traps and in gravid traps at the various parks.

Few national parks have mosquito surveillance programs and mosquito distribution within most parks is unknown. Adult mosquitoes were sampled using three types of traps: $CO_2$-baited CDC miniature light traps, gravid traps baited with an oak infusion, and gravid traps baited with a standard hay infusion. Also, mosquitoes that approached investigators while setting traps were collected. All specimens were identified and counted, and selected adults from the gravid traps were sent for viral testing.

*Coquillettidia perturbans*, an inefficient lab vector of WNV, was the most widely distributed species in CDC traps. Adults of this species were common at Acadia National Park, Saratoga National Historic Site, Minute Man National Historic Park, Cape Cod National Seashore, Roosevelt/Vanderbilt National Historic Site, and Delaware Water Gap National Recreation Area. *Ae. vexans,* a potential bridge vector of WNV, was common in Minute Man National Historic Park, Fire Island National Seashore, and Gateway National Recreation Area. *Cx. salinarius*, which has been implicated as an important bridge vector of WNV, was found at Fire Island National Seashore and Gateway National Recreation Area. *Ae. sollicitans*, also a potential bridge vector, was common at coastal parks with salt marsh habitat such as Acadia National Park, Fire Island National Seashore, and Gateway National Recreation Area.

Gravid traps effectively caught *Cx. pipiens* and *Cx. restuans*, both of which are competent enzootic vectors of WNV. *Cx. pipiens* was common in Saratoga National Historic Site, Minute Man National Historic Park, Cape Cod National Seashore, Delaware Water Gap National Recreation Area, Fire Island National Seashore, and Gateway National Recreation Area. *Cx. restuans* was found in Saratoga National Historic Site, Minute Man National Historic Park, Cape Cod National Seashore, Roosevelt/Vanderbilt National Historic Site, Delaware Water Gap National Recreation Area, and Gateway National Recreation Area.

The results of this study suggest that of the parks sampled, conditions were most suitable for WNV activity at Gateway National Recreation Area and Fire Island National Seashore. Both of these parks had substantial populations of enzootic vectors along with abundant species that are potential bridge vectors. Minute Man National Historic Park also had populations of enzootic and potential bridge vectors. The most common possible bridge vector at most of the other parks was *Cq. perturbans*, which has had low vector competence in lab trials. Although epidemic activity of WNV cannot be ruled out at these parks, the likelihood appears considerably lower than for Gateway and Fire Island. The only WNV-positive sample (of 116 mosquito pools tested) was a pool from Gateway National Recreation Area that contained one specimen of *Cx. pipiens*.

We compared sampling methods, including $CO_2$-baited CDC Miniature Light Traps, gravid traps baited with hay infusion, gravid traps with oak leaf infusion, and aerial sampling of adult mosquitoes approaching investigators. $CO_2$-baited CDC traps captured the most mosquitoes and the greatest diversity of mosquito species. The species most commonly collected in $CO_2$-baited CDC traps were *Ae. vexans*, *Ae. sollicitans*, *Cq. perturbans*, *Ae. canadensis*, and *Cx. salinarius*. Gravid traps baited with oak leaf infusion were the most effective at sampling *Cx. pipiens* and *Cx. restuans*. Gravid traps with different infusions shared 57.7% of the species collected, while the other sampling methods captured substantially

different species. The species that was most commonly captured approaching investigators was also the most common species in CDC traps on only 39.0 % of trap nights. Therefore, CDC trap captures do not always directly reflect the species biting people at a given time and place.

# Chapter I. Survey of mosquito species in eight northeastern national parks

## INTRODUCTION

West Nile virus (WNV), a mosquito-borne flavivirus in the Japanese Encephalitis group, is endemic to western Asia, Africa, and southern Europe (Hubálek & Halouzka 1996, Komar 2000, Lanciotti et al. 1999, Lundstrom 1999). It was first isolated from a human in the West Nile Province of Uganda in 1937 (CDC 1999, Komar 2000). WNV was first recorded in the Western Hemisphere in 1999, when an epidemic in New York City resulted in 62 cases of illness and seven fatalities (Enserink 2000). The strain of WNV in NY was similar to isolates from Israel (Lanciotti et al. 1999). During 2000 and 2001 WNV spread over much of the continental U.S. In 2002, WNV activity was documented in 44 states plus Washington, D.C. and 4,156 human cases were reported, which included 284 deaths (CDC 2002). There were 9,862 cases of WNV-associated illness reported in 2003 with 2,866 of them neuroinvasive, resulting in 232 fatalities (CDC 2005).

WNV is transmitted to humans through mosquito bites. Mosquitoes become infected after feeding on infected birds that have high viremias (high levels of WNV in their blood). WNV is passed from bird to bird in an enzootic cycle. In the eastern United States, this cycle is maintained by ornithophagic mosquitoes, especially *Culex restuans* (early in the season) and *Cx. pipiens* (through most of the summer). Bridge vectors are mosquitoes that have broad host ranges so they can pick up virus when feeding on infected birds, and later transmit WNV when they feed on humans or other animals (Komar 2000). Mosquitoes potentially involved in WNV transmission in eastern North America include *Cx. pipiens, Cx. restuans, Cx. salinarius, Ae. albopictus, Ae. japonicus, Ae. sollicitans,* and *Ae. vexans (*Sardelis et al. 2001, Sardelis & Turell 2001, Turell et al. 2001, 2005). In the 2000 outbreak in New York City, *Cx. pipiens* and *Cx. restuans* were apparently the major enzootic vectors, while *Cx. salinarius* was probably an important bridge vector (Kulasekera et al. 2001).

In the eastern United States WNV is most common in urban areas, but it can also occur in natural areas such as national parks. However, few national parks have mosquito surveillance programs and mosquito distribution within most parks is unknown. Knowledge of mosquito population trends and infection rates with arboviruses based on surveillance can be used to develop and implement management strategies for mosquitoes and WNV. The purpose of this survey is to assess the distribution and diversity of mosquito species and WNV infection in northeastern national parks, to provide baseline data for mosquito surveillance and to assess WNV risk.

Mosquito species were surveyed in eight national parks in the northeast. Most parks were sampled three times during the active mosquito season. Adult mosquitoes were sampled by collecting individuals that landed on investigators, and using three types of traps: $CO_2$-baited CDC miniature light traps, oak infusion-baited gravid traps, and hay infusion-baited gravid traps. All specimens were identified and counted and selected adults from the gravid traps were tested for arboviral infection.

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**Note:** Recent papers (Reinert 2000, Reinert et al. 2004) have proposed raising several subgenera within the genus *Aedes* to generic rank (e.g., *Ochlerotatus*, *Stegomyia*). Unfortunately, the basal relationships of these proposed genera remain poorly resolved. Therefore, in this report we utilize the traditional classification of the genus *Aedes* (e.g., Darsie & Ward 1981), as is currently utilized by the *Journal of Medical Entomology* (2005. *J. Med. Entomol.* 42: 511).

## MATERIALS AND METHODS

### National Parks

Mosquito species were surveyed in eight national parks in the Northeast. These sites are listed below.

1. Acadia National Park, ME:
   Acadia National Park comprises 18,616 ha (46,000 ac) on the rock-bound shore of Mount Desert Island, Maine. The geography of the park ranges from meadows and marshes to dense evergreen forests. This park was surveyed July 6-7 and August 9-10, 2001. The three sampling sites were: Seawall Campground, Thompson Island, and Eagle Lake. Seawall Campground, a forest area near a saltmarsh wetland, is located on southern Mount Desert Island. Thompson Island, also a saltmarsh wetland, is located on Northern Mount Desert Island. Eagle Lake is an open, fresh water wetland located near park headquarters.
2. Saratoga National Historical Park, NY:
   Saratoga National Historic Park is located in Stillwater, New York, on the Upper Hudson River. It contains 1,378 ha (3,406 ac), nearly half of which are deciduous woods. It was surveyed June 20-21, July 31-Aug 1, and Aug 28-29, 2001. The three sampling sites were: Service Pond Road, Old Champlain Canal, and the Schuylerville House Site.
3. Minute Man National Historical Park, MA:
   This park is situated 24 km (15 mi) northwest of Boston and encloses 391 ha (967 ac). Forests cover approximately 202 ha (500 ac) of the park, including nearly 81 ha (200 ac) of forested wetland. This park was surveyed June 28-29 and August 6-7, 2001. North Bridge Unit, Elm Brook Wetland, and Votech Wetland were the three sampling sites. The North Bridge Unit sample area is a swamp. Both Elm Brook Wetland and Votech Wetland are marsh areas.
4. Cape Cod National Seashore, MA:
   Cape Cod National Seashore comprises 17,646 ha (43,604 ac) of shoreline, with headquarters near Wellfleet, Massachusetts. It includes sandy beach, as well as pitch pine (*Pinus rigida*) and oak (*Quercus* spp.) woods, swamps and other wetlands, including numerous kettle ponds. This seashore was sampled June 25-26, August 2-3, and August 30-31, 2001. The three sample sites were: Atlantic White Cedar Swamp, Bound Brook, and Race Point. The Atlantic White Cedar Swamp is located in the southern area of the park, off Route 6. Bound Brook is located near the middle of the park and Race Point is in Provincetown, in the northern part of the park.
5. Roosevelt/Vanderbilt National Historic Sites, NY:
   These historic sites border the Hudson River in New York. Mosquitoes at this site were trapped June 19-20, July 30-31, and August 27-28, 2001. The three sample sites were the FDR site, Val-Kill (off road), and Val-Kill Pond. The FDR site includes a stagnant area off the FDR Ice Pond. Val-Kill (off road) and Val-Kill Pond are swamp areas.

6. Delaware Water Gap National Recreation Area, NY/NJ/PA:
   This recreation area encompasses 28,328 ha (70,000 ac) in New Jersey, Pennsylvania, and New York. It has ridges, forests, lakes, and streams on both sides of the Delaware River. The forests are mostly composed of secondary-growth and shrub thickets. This area was surveyed May 29-30, July 10-11, and August 12-13, 2001. North Contact Station, Pocono Environmental Education Center, and Depew Schoolhouse were the three sampling sites. North Contact Station is a deciduous woodland surrounding a depression with standing water. The Pocono Environmental Education Center includes oaks and red maples, with mosquito traps set near an area with restricted flow at one end of a stagnant pond. The Depew Schoolhouse site has swamp habitat with red maple and chestnut oak.
7. Fire Island National Seashore, NY:
   Fire Island is a barrier island off the South shore of Long Island, New York. There are no public roads to access its 52 km (32 mi) of beach and saltwater marshes. This seashore was sampled June 11-12, July 26-27, and August 21-22, 2001. The three sample sites were: Fire House Pond, Sunken Forest, and Hospital Point. Fire House Pond is a fresh water pond in the secondary dune area of the Lighthouse Tract, near the west end of the National Seashore. Sunken Forest is also in the secondary dune area, and has tree-sized American holly, shadbush, and sassafras in a deep swale, with areas of standing fresh water. Hospital Point, a site with extensive saltmarsh and standing fresh water, is near the east end of the National Seashore.
8. Gateway National Recreation Area, NY/NJ:
   This recreation area includes Sandy Hook in Northern New Jersey, small park sites in Staten Island, NY and the Jamaica Bay Unit in Brooklyn and Queens, NY. It was sampled June 5-6, July 16-17, and August 15-16, 2001. The sample sites were all near freshwater ponds, in wooded areas, in the Jamaica Bay Unit. Big John's Pond, a wooded wetland with emergent vegetation, is in Jamaica Bay Wildlife Refuge. Return a Gift Pond, is located along a nature trail near the North end of Floyd Bennett Field. Traps were also set at Breezy Point near a pond in a forested area, near the Western end of the barrier island at the entrance to New York Harbor.

**Sampling Agenda**

Each park was sampled three times during summer 2001, except Acadia National Park, ME and Minute Man National Historic Site, MA, which were sampled twice. Two days at a park site were required for sampling. Traps were set on day one, and mosquitoes approaching the investigators were collected. Trap catches were collected on day two, additional samples of flying mosquitoes were taken, and specimens were returned to the lab.

**Sampling Procedures**

Adults were sampled with three types of traps (John W. Hock Company, Gainesville, FL, USA): CDC miniature light traps (Model#512) baited with carbon dioxide (dry ice) (Sudia and Chamberlain 1962), gravid traps (Model#1712) baited with a high organic content hay

infusion, and gravid traps (Model#1712) baited with an oak-leaf infusion (Reiter 1983). Adult fliers were sampled by collecting mosquitoes that approached or landed on the investigators.

The hay infusion was made according to the recipe supplied by the John W. Hock Company, Gainesville, FL, USA by adding 0.083 kg (0.167 lb) of hay and 0.005 kg (0.011 lb) each of dried brewer's yeast and lactalbumin powder to 19.0 L (5.0 gal) of tap water. The hay infusion incubated for at least five days before use. The oak-leaf infusion was made by adding 0.635 kg (1.4 lbs) oak leaf litter to 19.0 L (5.0 gal) of tap water (O'Meara et al. 1989). It was allowed to incubate for at least five days.

Three sites at each park were selected for sampling. Sites were selected to include diverse habitat-types that potentially contain mosquitoes. One CDC trap, one hay infusion-baited gravid trap, and one oak infusion-baited gravid trap was placed at each of the three sample sites. Traps were placed in appropriate locations (gravid traps in depressions, near standing water if present; CDC traps hung from tree branches in protected areas) and were a few to several meters apart. Traps were set after 2:00 P.M. and by one hour before sunset. A 2.72 kg (6.0 lb) chunk of dry ice wrapped in three sheets of newspaper was hung next to each CDC light trap, level with the cap of the trap. The CDC traps were hung so the cap was approximately 1.37 m (4.5 ft) above the ground. Gravid traps were set by adding 2.7L (0.713 gal) of infusion liquid to green tubs. All trap samples were collected after one hour past sunrise and before 10:00 A.M. Adult mosquitoes from the traps and aerial samples were returned to URI in a cooler with dry ice (specimens were separated from the dry ice by several sheets of newspaper so that the specimens were anesthetized, but not frozen until placed in a freezer in the lab). All specimens were later identified to species and counted.

**Arbovirus Testing**

Adults from gravid trap samples were tested (laboratory of Dr. Tsutomu Takeda, Plant Sciences Department, University of Rhode Island, Kingston, RI, USA) for evidence of West Nile virus infection and other viral infections. Mosquito pools were tested for viruses using Vero cell plaque assays, followed by immunologic identification by IFA. Positive mosquito pools were also tested by RT-PCR. One pool of mosquitoes from each gravid trap was sent for viral testing. A pool consisted of 1-50 mosquitoes of one species, from a single trap. Species tested include *Cx. pipiens*, *Cx. restuans*, *Cx. salinarius*, *Ae. japonicus*, *Ae. vexans*, and *Cq. perturbans*. A few specimens from the selected pools were saved and frozen as vouchers to confirm the identification of the specimens sent in the pool.

## RESULTS

A total of 53,710 mosquitoes, representing 34 species, were collected in this survey. Mosquito species collected by CDC light traps are presented in Table 1. *Cq. perturbans*, the most widely distributed species, was abundant in Acadia National Park, Cape Cod National Seashore, Delaware Water Gap National Recreation Area, Minute Man National Historic Park, Saratoga National Historic Park, and Roosevelt/Vanderbilt National Historic Site. Also widely distributed, *Ae. vexans* was common at Fire Island National Seashore, Gateway National Recreation Area, and Minute Man National Historic Park. C*x. salinarius* was abundant at Fire Island National Seashore and Gateway National Recreation Area. *Cx. salinarius* was present, but less abundant, at Cape Cod National Seashore. Some species had limited distributions. For example, *Ae. punctor* was found only in Acadia National Park. *Ae. sollicitans*, a high salt marsh mosquito, was most abundant at Fire Island National Seashore.

Mosquito species caught in baited gravid traps are listed in Table 2. *Cx. pipiens* and *Cx. restuans* were abundant in gravid trap samples from all eight national parks. Gravid traps also caught *Ae. sollicitans* at Fire Island National Seashore. Adult landing samples most effectively captured aggressively biting species, such as *Ae. sollicitans* and *Ae. vexans.* Of the species most commonly approaching investigators, *Ae. vexans* was among the top two species at four parks (DEWA, FIIS, GATE, MIMA), *Ae. sollicitans* at three parks (ACAD, FIIS, GATE), with two parks each for *Cq. perturbans* (MIMA, SARA), *Ae. cantator* (ACAD, CACO), and *Ae. excrucians* (DEWA, ROVA) [abbreviations for park names as in Table 3].

A total of 116 pools were sent for testing (Table 3). Thirteen species were represented in the tested pools. Only one pool tested positive for West Nile virus. The positive pool contained one *Cx. pipiens* mosquito that was trapped on August 15, 2001 at the Breezy Point site in Gateway National Recreation Area.

Table 1: Mosquitoes caught in $CO_2$-baited CDC light traps in eight national parks expressed as means per trap night (± standard error).

| Species | Acadia | Cape Cod | Delaware WG | Fire Island | Gateway | Minute Man | Roosevelt/ Vanderbilt | Saratoga |
|---|---|---|---|---|---|---|---|---|
| *Aedes vexans* | 2.0(±0.5) | 0.9(±0.7) | 0.11(±0.11) | 244.26(±242.3) | 103.1(±101.2) | 714.0(±689.8) | 3.59(±3.54) | 1.44(±1.33) |
| *Aedes hendersoni*? | | | | | | 1.0(±1.0) | | |
| *Aedes* spp. | 1.7(±1.5) | 0.7(±0.7) | 0.41(±0.30) | 1.07(±0.26) | 5.63(±3.48) | 18.0(±15.0 | 1.93(±1.76) | 5.00(±3.36) |
| *Anopheles earlei* | 0.08(±0.08) | | | | | | | |
| *Anopheles punctipennis* | 0.6(±0.3) | 0.4(±0.2) | 0.52(±0.10) | | 0.19(±0.07) | 35.75(±25.25) | 4.85(±2.70) | 1.41(±0.33) |
| *Anopheles quadrimaculatus* | 0.3(±0.08) | 0.07(±0.04) | 0.04(±0.04) | 0.11(±0.06) | 0.52(±0.29) | 2.0(±0.50) | 1.26(±0.52) | 0.41(±0.16) |
| *Anopheles* spp. | | | | 0.04(±0.04) | | | 0.04(±0.04) | 0.11(±0.06) |
| *Anopheles walkeri* | 0.17(±0.17) | | | | | | | 0.07(±0.07) |
| *Coquillittidia perturbans* | 55.8(±55.8) | 102.7(±0.04) | 2.4(±1.87) | 0.07(±0.07) | 0.11(±0.11) | 362.8(±302.3) | 31.11(±16.46) | 58.63(±36.3) |
| *Culiseta impatiens* | 0.67(±0.17) | 3.3(±3.3) | | | | 5.33(±2.33) | 0.04(±0.04) | |
| *Culiseta melanura* | | 3.7(±1.3) | | | | 1.5(±1.5) | 0.07(±0.04) | |
| *Culiseta morsitans* | | | | | | 0.25(±0.25) | 0.04(±0.04) | 0.11(±0.11) |
| *Culiseta* spp. | | 0.4(±0.4) | | 0.04(±0.04) | | 1.33(±0.50) | | |
| *Culex pipiens* | | 0.81(±0.56) | 0.22(±0.11) | 0.67(±0.28) | 2.3(±1.77) | 3.42(±1.92) | 0.19(±0.13) | 0.22(±0.13) |
| *Culex restuans* | 0.3(±0.17) | 1.4(±1.3) | 0.22(±0.22) | | 0.48(±0.48) | 1.50(±0.33) | 0.15(±0.15) | 0.15(±0.10) |
| *Culex salinarius* | | 1.3(±0.73) | | 15.19(±8.56) | 20.33(±9.71) | 0.17(±0.17) | 0.07(±0.07) | |
| *Culex* spp. | 0.08(±0.08) | 0.15(±0.15) | 0.11(±0.11) | 2.33(±0.94) | 3.74(±3.0) | 3.42(±2.92) | 0.04(±0.04) | 0.26(±0.21) |
| *Culex territans* | | | | | 0.07(±0.04) | 0.75(±0.58) | | |
| *Aedes abserratus* | | 0.8(±0.8) | | | | | | |

Table 1: Mosquitoes caught in $CO_2$-baited CDC light traps in eight national parks expressed as means per trap night (± standard error) (continued).

| Species | Acadia | Cape Cod | Delaware WG | Fire Island | Gateway | Minute Man | Roosevelt/ Vanderbilt | Saratoga |
|---|---|---|---|---|---|---|---|---|
| *Aedes aurifer*? | | 6.3(±6.3) | | | | 5.75(±5.75) | | |
| *Aedes canadensis* | 11.1(±6.8) | 17.6(±11.8) | 0.07(±0.07) | 0.04(±0.04) | 0.07(±0.07) | 29.0(±19.83) | 1.37(±0.84) | 1.30(±1.24) |
| *Aedes cantator* | 20.1(±18.3) | 12.6(±9.1) | | 5.85(±5.41) | 2.33(±0.74) | 1.75(±1.75) | 0.33(±0.33) | 0.59(±0.59) |
| *Aedes cinereus*? | 0.5(±0.5) | 1.2(±1.2) | 0.04(±0.04) | | 0.63(±0.63) | 9.83(±4.17) | 0.37(±0.32) | 0.04(±0.04) |
| *Aedes excrucians* | 2.0(±0.8) | 4.2(±3.1) | 0.04(±0.04) | 0.04(±0.04) | | 5.17(±5.17) | 0.59(±0.54) | 1.41(±1.41) |
| *Aedes implicatus*? | | | | | | | | 1.78(±1.78) |
| *Aedes intrudens*? | | | | | | 5.0(±5.0) | | |
| *Aedes punctor* | 26.3(±26.3) | | | | | | | |
| *Aedes riparius*? | 0.3(±0.3) | | | 0.07(±0.07) | | | | |
| *Aedes sollicitans* | 11.5(±5.2) | | | 508.3(±255.6) | 6.89(±2.82) | | 0.22(±0.13) | |
| *Aedes sticticus?* | | | 0.22(±0.22) | | | | | 0.07(±0.07) |
| *Aedes taeniorhynchus* | | | | 6.44(±3.15) | 0.22(±0.22) | | | |
| *Aedes triseriatus* | | | | | | 0.17(±0.0) | 0.30(±0.30) | |
| *Aedes trivittatus* | | | 3.04(±2.98) | | 0.44(±0.44) | | 8.07(±7.36) | 6.52(±6.52) |
| *Psorophora ciliata* | | | | 1.30(±1.03) | | | | |
| *Psorophora ferox* | | 0.04(±0.04) | | | | | 0.04(±0.04) | |
| *Uranotaenia sapphirina* | | 1.7(±1.6) | 3.7(±3.30) | | 1.04(±0.98) | 4.75(±4.75) | 1.0(±0.11) | 1.37(±1.04) |

Cell values represent mean number of mosquitoes per trap night (± standard error). Identifications of species with question marks (?) were not confirmed.

Table 2: Mosquitoes caught in gravid traps in eight national parks expressed as means per trap night (+ standard error).

| | Park | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Species** | **Acadia** | **Cape Cod** | **Delaware WG** | **Fire Island** | **Gateway** | **Minute Man** | **Roosevelt/ Vanderbilt** | **Saratoga** |
| *Aedes vexans* | | | | 0.44(±0.28) | 0.11(±0.11) | 2.58(±2.58) | | |
| *Aedes* spp. | | 0.33(±0.25) | 0.39(±0.24) | 0.22(±0.15) | 0.06(±0.06) | 0.75(±0.75) | 0.17(±0.17) | 0.06(±0.06) |
| *Anopheles punctipennis* | | | | 0.06(±0.06) | | | | 0.06(±0.06) |
| *Anopheles quadrimaculatus* | | | | 0.28(±0.15) | | | 0.06(±0.06) | 0.11(±0.11) |
| *Coquillittidia perturbans* | 0.25 (±0.25) | 0.17(±0.17) | 0.06(±0.06) | | | 0.50(±0.17) | | 0.44(±0.36) |
| *Culiseta impatiens* | | 0.06(±0.06) | | 0.06(±0.06) | | 0.08(±0.08) | | |
| *Culiseta melanura* | | 0.06(±0.06) | | | | 0.17(±0.00) | 0.06(±0.06) | |
| *Culex pipiens* | 0.58(±0.08) | 1.33(±0.86) | 6.06(±5.97) | 8.94(±7.56) | 26.28(±16.73) | 11.17(±5.33) | 1.56(±0.78) | 4.89(±2.46) |
| *Culex restuans* | 1.80(±0.50) | 1.11(±0.62) | 2.72(±0.89) | 0.44(±0.36) | 20.44(±17.90) | 8.67(±5.67) | 2.67(±1.07) | 7.78(±2.98) |
| *Culex salinarius* | | | | | | 0.08(±0.08) | | |
| *Culex* spp. | 0.33(±0.33) | 0.56(±0.56) | 7.72(±7.07) | 1.72(±1.23) | 10.44(±4.42) | 2.92(±1.75) | 0.72(±0.36) | 2.39(±0.86) |
| *Culex territans* | 0.25 (±0.25) | 0.1(±0.3) | 0.06(±0.06) | | 0.28(±0.15) | 1.42(±1.08) | | 0.11(±0.11) |
| *Aedes canadensis* | | 0.39(±0.31) | | | | 0.50(±0.00) | 0.17(±0.17) | |
| *Aedes cantator* | 0.08(±0.08) | 0.11(±0.11) | | | | | | |
| *Aedes cinereus?* | | | | | 0.39(±0.31) | 0.75(±0.25) | | |
| *Aedes excrucians* | | 0.06(±0.06) | | | | | | |
| *Aedes japonicus* | | | | | | | | 0.28(±0.20) |
| *Aedes punctor* | 0.08(±0.08) | | | | | | | |
| *Aedes sollicitans* | 0.33(±0.00) | | | 17.72(±16.07) | 0.61(±0.61) | | | |
| *Aedes sticticus?* | | | | | | | | 0.22(±0.22) |
| *Aedes stimulans?* | | | | | | | | 0.89(±0.89) |
| *Aedes trivittatus* | | | | | | | | 0.06(±0.06) |
| *Psorophora* sp. | | | | | | | | 0.06(±0.06) |
| *Uranotaenia sapphirina* | | 0.06(±0.06) | 0.17(±0.10) | | 0.44(±0.44) | 1.00(±1.00) | 0.11(±0.11) | 0.28(±0.28) |

Cell values represent mean number of mosquitoes per trap night (± standard error). Identifications for species with question marks were not confirmed.

Table 3. Mosquitoes from eight national park unit tested for viral infection.

| PARK | DATE | SPECIES | #/POOL | # POOLS | P/N * |
|---|---|---|---|---|---|
| **Acadia National Park, ME** | 7-Jul-01 | *Coquillettidia perturbans* | 2 | 1 | N |
| | | *Aedes sollicitans* | 1 | 1 | N |
| | | *Aedes cantator* | 1 | 1 | N |
| | | *Culex spp.* | 3 | 1 | N |
| | | *Culex restuans* | 4 | 2 | N |
| | 10-Aug-01 | *Aedes sollicitans* | 1 | 1 | N |
| | | *Culex territans* | 1 | 2 | N |
| | | *Culex restuans* | 6 | 1 | N |
| **Cape Cod National Seashore, MA** | 26-Jun-01 | *Coquillettidia perturbans* | 1 | 1 | N |
| | | *Culex restuans* | 5 | 2 | N |
| | | *Culex restuans* | 2 | 1 | N |
| | | *Aedes canadensis* | 1 | 1 | N |
| | | *Aedes cantator* | 2 | 1 | N |
| | 3-Aug-01 | *Culex pipiens* | 2 | 1 | N |
| | | *Culex pipiens* | 1 | 1 | N |
| | | *Culex restuans* | 1 | 1 | N |
| | | *Culex territans* | 1 | 1 | N |
| | 31-Aug-01 | *Culex pipiens* | 13 | 1 | N |
| | | *Culex pipiens* | 2 | 1 | N |
| | | *Culex restuans* | 1 | 2 | N |
| | | *Uranotaenia sapphirina* | 1 | 1 | N |
| **Delaware Water Gap National Recreation Area, NY/NJ/PA** | 30-May-01 | *Culex restuans* | 2 | 1 | N |
| | | *Culex restuans* | 4 | 1 | N |
| | | *Culex restuans* | 3 | 1 | N |
| | 11-Jul-01 | *Culex pipiens* | 1 | 1 | N |
| | | *Culex pipiens* | 2 | 1 | N |
| | | *Culex spp.* | 16 | 1 | N |
| | | *Culex spp.* | 1 | 1 | N |
| | | *Culex spp.* | 50 | 1 | N |
| | | *Culex spp.* | 3 | 1 | N |
| | 13-Aug-01 | *Culex pipiens* | 1 | 1 | N |
| | | *Culex restuans* | 4 | 1 | N |
| | | *Culex restuans* | 5 | 1 | N |
| | | *Culex spp.* | 1 | 2 | N |

Table 3. Mosquitoes from eight national park unit tested for viral infection (continued).

| | | | | | |
|---|---|---|---|---|---|
| **Fire Island National Seashore** | 13-Jun-01 | *Aedes vexans* | 4 | 1 | N |
| | | *Culex restuans* | 1 | 1 | N |
| | | *Culex* spp. | 26 | 1 | N |
| | | *Culex* spp. | 1 | 1 | N |
| | | *Aedes sollicitans* | 45 | 1 | N |
| | | *Aedes sollicitans* | 14 | 1 | N |
| | 27-Jul-01 | *Culex pipiens* | 39 | 1 | N |
| | | *Culex pipiens* | 13 | 1 | N |
| | | *Culex pipiens* | 49 | 1 | N |
| | | *Culex pipiens* | 24 | 1 | N |
| | | *Culex* spp. | 5 | 1 | N |
| | 22-Aug-01 | *Culex pipiens* | 2 | 1 | N |
| | | *Culex pipiens* | 6 | 1 | N |
| | | *Culex pipiens* | 1 | 1 | N |
| | | *Culex* spp. | 2 | 1 | N |
| | | *Aedes sollicitans* | 5 | 1 | N |
| **Gateway National Recreation Area, NY/NJ** | 6-Jun-01 | *Culex restuans* | 6 | 1 | N |
| | | *Culex restuans* | 3 | 1 | N |
| | | *Culex restuans* | 31 | 1 | N |
| | | *Culex restuans* | 21 | 1 | N |
| | | *Culex restuans* | 10 | 1 | N |
| | | Aedes sollicitans | 7 | 1 | N |
| | 17-Jul-01 | *Culex pipiens* | 17 | 1 | N |
| | | *Culex pipiens* | 50 | 2 | N |
| | | *Culex pipiens* | 9 | 1 | N |
| | | *Culex pipiens* | 7 | 1 | N |
| | | *Culex pipiens* | 39 | 1 | N |
| | **15-Aug-01** | *Culex pipiens* | 46 | 1 | N |
| | | *Culex pipiens* | 29 | 1 | N |
| | | *Culex pipiens* | 8 | 1 | N |
| | | ***Culex pipiens*** | **1** | **1** | **P** |
| | | *Culex pipiens* | 3 | 1 | N |
| **Minute Man National Historical Park, MA** | 29-Jun-01 | *Aedes vexans* | 28 | 1 | N |
| | | *Coquillettidia perturbans* | 2 | 1 | N |
| | | *Culex pipiens* | 1 | 2 | N |
| | | *Culex pipiens* | 14 | 1 | N |
| | 7-Aug-01 | *Culex pipiens* | 2 | 1 | N |
| | | *Culex restuans* | 8 | 1 | N |
| | | *Culex restuans* | 15 | 1 | N |
| | | *Culex restuans* | 36 | 1 | N |
| | | *Culex restuans* | 4 | 1 | N |

Table 3. Mosquitoes from eight national park unit tested for viral infection (continued).

| | | | | | |
|---|---|---|---|---|---|
| **Roosevelt/Vanderbilt National Historic Site, NY** | 20-Jun-01 | *Culex restuans* | 11 | 1 | N |
| | | *Culex restuans* | 3 | 1 | N |
| | | *Culex restuans* | 1 | 1 | N |
| | | *Culex restuans* | 7 | 1 | N |
| | | *Aedes canadensis* | 1 | 1 | N |
| | 31-Jul-01 | *Culiseta melanura* | 1 | 1 | N |
| | | *Culex pipiens* | 1 | 2 | N |
| | | *Culex pipiens* | 2 | 1 | N |
| | | *Culex restuans* | 11 | 1 | N |
| | | *Culex restuans* | 3 | 1 | N |
| | 28-Aug-01 | *Culex pipiens* | 5 | 1 | N |
| | | *Culex pipiens* | 7 | 1 | N |
| | | *Culex restuans* | 2 | 1 | N |
| | | *Uranoteania sapphirina* | 2 | 1 | N |
| **Saratoga National Historic Park, NY** | 21-Jun-01 | *Coquillettidia perturbans* | 4 | 1 | N |
| | | *Culex restuans* | 15 | 1 | N |
| | | *Culex restuans* | 6 | 1 | N |
| | | *Aedes stimulans* | 4 | 1 | N |
| | | *Psorophora cyanescens* | 1 | 1 | N |
| | 1-Aug-01 | *Culex pipiens* | 1 | 1 | N |
| | | *Culex pipiens* | 2 | 1 | N |
| | | *Culex pipiens* | 19 | 1 | N |
| | | *Culex pipiens* | 7 | 1 | N |
| | | *Culex pipiens* | 5 | 1 | N |
| | | *Culex pipiens* | 4 | 1 | N |
| | 29-Aug-01 | *Culex pipiens* | 9 | 1 | N |
| | | *Culex pipiens* | 6 | 1 | N |
| | | *Culex pipiens* | 5 | 1 | N |
| | | *Culex restuans* | 24 | 1 | N |
| | | *Aedes japonicus* | 1 | 1 | N |
| | | *Aedes japonicus* | 2 | 1 | N |
| | | *Uranotaenia sapphirina* | 1 | 1 | N |

* N = negative, P = positive

## DISCUSSION

Specific local conditions increase the likelihood of epizootic activity of WNV. First, there must be competent enzootic mosquito vectors and avian reservoir hosts. Primary vector species vary with geographic location. In general, *Culex* species are the most important vectors and birds are important vertebrate reservoirs. Additionally, the enzootic vector and reservoir bird populations must overlap with those of potential bridge vectors (Komar 2000). However, largely because of the brief period of time that this virus has been present in North America, the ecological dynamics of the WNV cycle in nature are not yet well understood.

CDC light traps catch numerous mosquito species, many of which are capable of transmitting WNV. In this study, *Cq. perturbans*, a univoltine species, was the most widely distributed species in CDC traps. Adults of this species were common at Acadia National Park, Saratoga National Historic Park, Minute Man National Historic Park, Cape Cod National Seashore, Roosevelt/Vanderbilt National Historic Site, and Delaware Water Gap National Recreation Area. In lab trials, *Cq. perturbans* was an inefficient vector of WNV with an estimated transmission rate (ETR) of only 2%. Estimated transmission rate is the percentage of mosquitoes that developed a disseminated infection after ingesting WNV multiplied by the percentage of mosquitoes with disseminated infection that transmitted virus by bite (Sardelis et al. 2001). However, ETR was calculated through lab trials under constant conditions and might not apply directly to field conditions. ETR was used for reasoning about the likelihood of WNV transmission in each park, but local conditions could modify transmission dynamics in the field (Sardelis et al. 2001, Turell et al. 2001, 2005). Despite its low competence, *Cq. perturbans* could potentially transmit WNV at low levels under appropriate conditions (Sardelis et al. 2001).

*Ae. vexans* was common in Minute Man National Historic Park, Fire Island National Seashore, and Gateway National Recreation Area. West Nile virus was naturally isolated from *Ae. vexans* in New York during 1999 (Sardelis et al. 2001). This species has an ETR of 8%. Although this percentage is moderately low, *Ae. vexans* can transmit WNV by bite and can serve as a bridge vector (Turell et al 2001, 2005), especially in view of the abundance and aggressive biting behavior of this species. *Cx. salinarius* was regularly found in Fire Island National Seashore and Gateway National Recreation Area, and WNV was naturally isolated from this species in New York during 2000. *Cx. salinarius* efficiently transmits WNV by bite (ETR of 34%), and might be an important bridge vector between the enzootic avian cycle of WNV and mammalian hosts (Kulasekera et al. 2001, Sardelis et al. 2001). *Ae. sollicitans* was common at coastal parks with salt marsh habitat, including Acadia National Park, Fire Island National Seashore (Ginsberg 1986), and Gateway National Recreation Area. This species can potentially serve as a bridge vector because it feeds on mammals (≥95%) and birds (≤5%) (Crans 1977). *Ae. sollicitans* is moderately susceptible to WNV infection and has an ETR of 11% (Turell et al. 2001).

Infusion-baited gravid traps efficiently caught *Cx. pipiens* and *Cx. restuans*, both of which transmit WNV. *Cx. pipiens* was common in Saratoga National Historic Park, Minute Man National Historic Park, Cape Cod National Seashore, Delaware Water Gap National Recreation Area, Fire Island National Seashore, and Gateway National Recreation Area. *Cx. pipiens* has an ETR of 20%. It is an efficient enzootic vector of WNV that feeds primarily on avian hosts (Turell et al. 2001), but it might also play a role as a bridge vector (Kilpatrick et al. 2005). This species is abundant from June into September. *Cx. restuans*, another ornithophagic species that is active from spring into June, was common in Saratoga National Historic Site, Minute Man National Historic Park, Cape Cod National Seashore, Roosevelt/Vanderbilt

National Historic Site, Delaware Water Gap National Recreation Area, and Gateway National Recreation Area. *Cx. restuans* has an ETR of 55%, and it probably serves primarily as an enzootic vector of WNV in the spring (Sardelis et al. 2001).

Adult aerial samples caught potential bridge vector species (especially aggressive biting species) such as *Ae. vexans* and *Ae. sollicitans*, but the species captured did not always match the predominant species in nearby CDC trap samples (see Chapter II).

The parks surveyed in this study were only sampled two or three times during the summer of 2001. Therefore, our data are limited and might not be thoroughly representative of mosquito populations in the eight national parks. Specifically, some important vector species that were present might not have been well represented at some parks because of limited sampling and sampling bias. Nevertheless, the results suggest that of the parks sampled, conditions were most suitable for WNV activity at Gateway National Recreation Area and Fire Island National Seashore. Both of these parks had substantial populations of enzootic vectors (*Cx. pipiens* and *Cx. restuans*) along with abundant species that are potential bridge vectors (*Cx. salinarius, Ae. vexans,* and *Ae. sollicitans*). Minute Man National Historic Park also had populations of enzootic and potential bridge vectors. The most common possible bridge vector at most of the other parks was *Cq. perturbans*, which had low vector competence in lab trials (Sardelis et al. 2001, Turell et al. 2005). Although epidemic activity of WNV cannot be ruled out at these parks, the likelihood appears to be lower than it is for Gateway and Fire Island. These results are compatible with surveillance data, which have detected numerous WNV-positive mosquito pools from Gateway National Recreation Area and Fire Island National Seashore, but few from any of the other parks. The only positive pool in this study contained one *Cx. pipiens* mosquito captured in the vicinity of Breezy Point at Gateway National Recreation Area.

# Chapter II. Trapping biases in $CO_2$-baited CDC light trap and infusion-baited gravid trap samples

## INTRODUCTION

Numerous types of mosquito traps are utilized in mosquito and arboviral surveillance programs. The CDC miniature light trap (Sudia and Chamberlain 1962) is a portable and efficient method of collecting host-seeking mosquitoes. Infusion-baited gravid traps are also portable, and are designed to attract gravid females of species that oviposit in water with high organic content (Reiter 1983). In addition, mammalophagic adult mosquitoes can be sampled with landing/biting counts (Slaff et al. 1983). These methods are widely used for mosquito sampling and arboviral surveillance and many studies have assessed their efficacy (Service 1993). However, few studies have compared catches of these collection methods in replicated trials in diverse habitats.

In this study, we compared these mosquito sampling methods in a survey of eight national park sites in the northeastern U.S. Adult mosquitoes were surveyed by collecting individuals that approached or landed on investigators, and using three types of traps: $CO_2$-baited CDC miniature light traps, gravid traps baited with an oak infusion, and gravid traps baited with a hay infusion. All specimens were counted and identified. These replicated samples are used to assess the efficacies of these trapping methods at sampling various mosquito species, with particular reference to potential vectors of arboviruses in the northeastern states.

## MATERIALS AND METHODS

Cape Cod and Fire Island National Seashores, Gateway and Delaware Water Gap National Recreation Areas, and Roosevelt-Vanderbilt and Saratoga National Historic Parks were each sampled three times, while Acadia National Park and Minute Man National Historic Site were each sampled twice in 2001.

Trapping methods are described in Chapter I. All specimens collected were identified to species and counted. Specimens were identified using standard keys (Stojanovich 1961, Means 1979, 1983, Darsie & Ward 1981). *Culex restuans*, *Cx. pipiens*, and *Cx. salinarius* were distinguished by the pattern of basal scale bands on the abdominal terga, by the presence or absence of white scutal spots, color of scutellar scales, and presence or absence of white scales medially on abdominal tergum VII (Andreadis et al. 2005). Questionable specimens were recorded as "*Culex* sp." and were excluded from the analysis.

Species diversity in trap catches was compared by analyzing the two components of diversity: species richness and evenness. Species richness, which is the number of species collected, was calculated to compare the five trapping methods used in the eight national parks. Species evenness was estimated with a modified version of Simpson's Index (Southwood 1968): Evenness = $1 - \Sigma_i p_i^2$ where $p_i = n_i / N$ for each species $i$, $n_i$ = the number of individuals of species $i$, and $N$ = the total number of individuals in the sample. Simpson's Index is sometimes used as an estimate of diversity, with both species richness and evenness contributing to its value. However, $p_i^2$ is roughly the probability that if two individuals are selected at random from the sample, they will be the same species. Intuitively, this is related to dominance of that species, so one minus this index is related to evenness. Therefore, we used this index as a rough measure of evenness, along with number of species per sample as a direct measure of species richness. A two-way ANOVA (SPSS 11.5, 2002) was used to analyze trends in species evenness between trap types at all parks. Differences in trap catches for *Ae. sollicitans* were also analyzed using a two-way ANOVA, but only for the three parks at which this species was common (Acadia National Park, Fire Island National Seashore, and Gateway National Recreation Area).

A comparison of shared species using Jaccard's Index (Jaccard 1912) was conducted for all five trapping techniques. Jaccard Index = $j/(a+b-j)$ ; where, $j$ = number of species shared by the two sampling methods, $a$ = number of species captured by sample method A, and $b$ = number of species captured by sample method B.

## RESULTS

Of the four sampling methods, the CDC traps caught the highest number of species ($F= 30.883$, $df= 4,35$, $p<0.001$) (Table 4). The species most commonly collected in CDC traps were *Ae. vexans*, *Ae. sollicitans*, and *Cq. perturbans*, with substantial numbers of *Cx. salinarius*, *Ae. canadensis, Ae. cantator*, and *Anopheles punctipennis*. Species evenness was not significantly different among trap types (first sampling round: $F=0.935$, $df=2,48$, $p=0.400$; second sampling round: $F=1.177$, $df=2,48$, $p=0.317$; third sampling round: $F=0.034$, $df=2,36$, $p=0.967$). Therefore, species diversity was greatest in the $CO_2$-baited CDC light trap collections, which caught the most species. Trap types also differed in terms of the number of individuals captured ($F=22.746$, $df=2,21$, $p=0.0000055$), with CDC traps capturing the most individuals (50,200 captured in CDC traps, compared to 2,198 in oak-infused and 872 in hay-infused gravid traps).

Trap captures for three common *Culex* species caught in $CO_2$-baited CDC light traps, oak-baited gravid traps, and hay-baited gravid traps are shown in Figure 1. Different types of traps collected substantially different *Culex* species (round 1: $F=2.513$, $df=4,144$, $p=0.044$; round 2: $F=13.980$, $df=4,144$, $p<0.001$; round 3: $F=4.221$, $df=4, 108$, $p=0.003$), with *Cx. pipiens/restuans* collected effectively by gravid traps, but *Cx. salinarius* collected primarily in $CO_2$-baited CDC light traps (Figure 1). Trap types also differed significantly in collections of *Ae. vexans* ($F=3.825$, $df=2,42$, $p=0.03$), *Cq. perturbans* ($F=7.536$, $df=2,42$, $p=0.002$), and *Ae. sollicitans* (Fire Island: $F=3.865$, $df=2,18$, $p=0.04$; Acadia: $F=5.456$, $df=2,12$, $p=0.021$; Gateway: $F=6.745$, $df=2,17$, $p=0.007$), with $CO_2$-baited CDC light traps being most effective at capturing all three species. The *Ae. sollicitans* captures, however, showed a significant interaction between sample type and trap site for all three parks at which this species was common (Fire Island NS: $F=3.837$, $df=4,18$, $p=0.020$; Acadia NP: $F=5.613$, $df=2,12$, $p=0.019$; Gateway NRA: $F=4.234$, $df=4, 17$, $p=0.015$).

In general, different sampling techniques collected different portions of the mosquito fauna, with most methods sharing less than one third of the species collected (Figure 2). The only sampling techniques that collected substantially the same species were the hay-baited and oak-baited gravid traps, which shared 57.7% of the species collected. The species collected in CDC traps differed substantially from those captured aerially while approaching investigators as they set the traps. Of the 41 trap nights for which we have samples from both CDC traps and aerial collections, the same species was most common in both sample types on only 16 nights (39.0%), and at least one species was among the top three species in each sample type on 27 nights (65.9%).

Table 4: Species richness in mosquito collections expressed as mean number of species per trap night (± standard error).

| | CDC light trap | | Hay-gravid trap | | Oak-gravid trap | |
|---|---|---|---|---|---|---|
| Park | total # species | mean # species/ trap night | total # species | mean # species/ trap night | total # species | mean # species/ trap night |
| Acadia NP | 15 | 4.2 (± 0.5) | 5 | 1.2 (± 0.2) | 5 | 1.2 (± 0.2) |
| Saratoga NP | 16 | 1.1 (± 0.3) | 7 | 0.4 (± 0.04) | 11 | 0.6 (± 0.1) |
| Roosevelt/Vanderbilt NHS | 18 | 1.3 (± 0.3) | 5 | 0.3 (± 0.04) | 4 | 0.3 (± 0.04) |
| Gateway NRA | 15 | 1.1 (± 0.1) | 7 | 0.4 (± 0.1) | 6 | 0.4 (± 0.1) |
| Delaware Water Gap NRA | 12 | 0.7(± 0.2) | 4 | 0.2 (± 0.1) | 4 | 0.3 (± 0.04) |
| Cape Cod NS | 17 | 1.4 (± 0.2) | 7 | 0.3 (± 0.1) | 6 | 0.3 (± 0.0) |
| Fire Island NS | 13 | 1.0 (± 0.1) | 5 | 0.4(± 0.1) | 7 | 0.4 (± 0.04) |
| Minute Man NHP | 20 | 2.7 (± 0.3) | 8 | 1.0 (± 0.2) | 11 | 1.3 (± 0.3) |

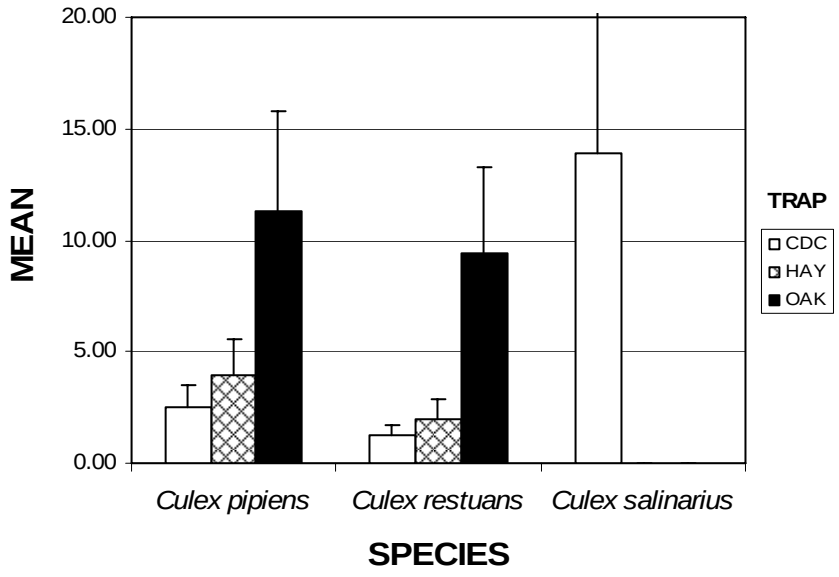


Figure 1. Comparison of trap catches for *Cx. pipiens, Cx. restuans,* and *Cx. salinarius* in $CO_2$-baited CDC light traps, hay infusion-baited gravid traps, and oak infusion-baited gravid traps in eight national parks. Values are mean numbers per trap night ($\pm$ standard error).

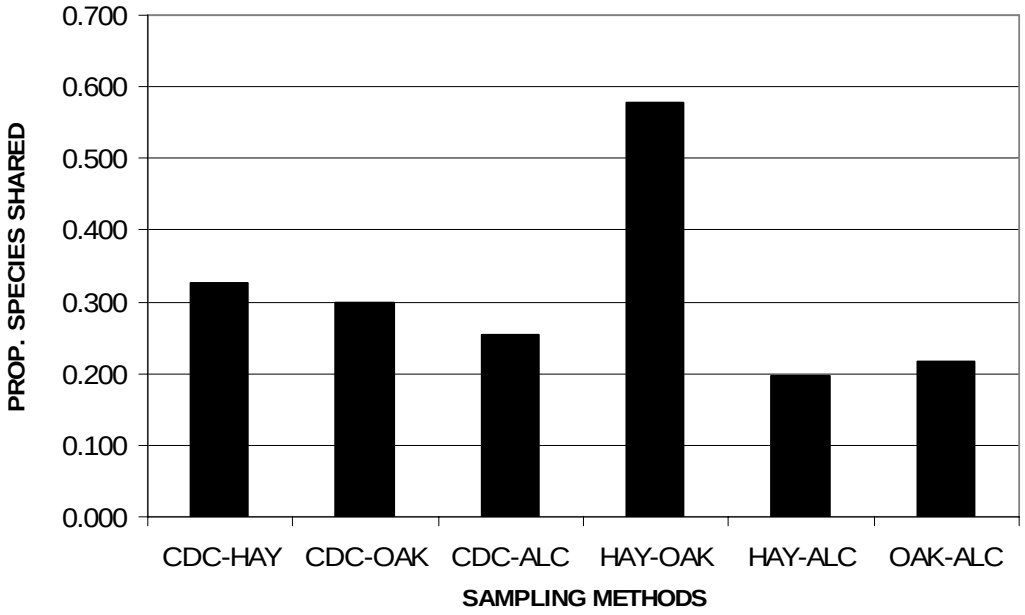


Figure 2. Jaccard Index of shared species for $CO_2$-baited CDC light traps (CDC), oak infusion-baited gravid traps (OAK), hay infusion-baited gravid traps (HAY), and adult landing samples (ALC) in eight national parks.

## DISCUSSION

CDC Miniature light traps baited with $CO_2$ are widely used in vector surveillance, and are known to capture a broad diversity of mosquito species (Service 1993). These traps captured the most individuals and the greatest diversity of mosquito species in our samples (Table 4), and were specifically adept at capturing several potential epidemic vectors of arboviruses such as WNV. Effectiveness at capturing *Cx. salinarius* is especially notable, because with an Estimated Transmission Rate (ETR) of 34% in lab trials (Turell et al. 2001) this species is a prime potential bridge vector for WNV in the northeast (Kulasekera et al. 2001, Andreadis et al. 2004). *Cx. restuans* and *Cx. pipiens*, which are primarily enzootic vectors of WNV, can also act as bridge vectors (Andreadis et al. 2004, Kilpatrick et al. 2005) and are also collected in CDC trap samples (Figure 1). Other potential bridge vectors, including *Ae. vexans* (ETR 9%), *Ae. sollicitans* (ETR 11%), and *Cq. perturbans* (ETR 2%) (Turell et al. 2001, 2005, Sardelis et al. 2001) were also sampled effectively by these traps. *Aedes albopictus* was not found at any of the sites in this survey, although as a day-biter this species is most likely not sampled effectively using light traps (Service 1993).

Gravid traps were most effective at sampling *Cx. pipiens* and *Cx. restuans* (Figure 1), both potential enzootic vectors of WNV. Collecting gravid females of these species would provide an efficient approach to detect the presence of WNV at a site. The greater attractiveness of the oak than the hay infusion in our samples could have resulted from greater organic content in the oak infusion recipe we used (O'Meara et al. 1989) relative to the hay infusion bait, or it might have resulted from some inherent feature (e.g., chemical attractant) in the oak leaves. This question is worth additional study because the relative ease of preparing oak leaf infusions suits them for use in broad surveillance programs. Lampman & Novak (1996) found that oak infusion attracted *Ae. albopictus* at comparable levels to a sod infusion that they were testing, suggesting that within its range, gravid traps baited with oak infusion would effectively sample this species as well.

The two infusion mixtures attracted substantially the same mosquito species (Figure 2), but none of the other sampling methods captured the same mix of species. The fact that $CO_2$-baited CDC light traps shared only about 25.4% of the species captured with samples of mosquitoes approaching the investigators while they set the traps (Figure 2), suggests that trap catches cannot dependably determine the mix of species that are actually biting humans at a site. Undoubtedly, the greater number of species collected by the CDC traps relative to the brief samples of flying mosquitoes approaching investigators contributed to the differences in the species collected. Furthermore, CDC light traps readily collected bird-feeding as well as mammal-feeding species. Finally, differences in the timing of sampling might have contributed to these differences because mosquitoes approaching investigators were collected only during late afternoon and early morning, while the traps ran all night. Nevertheless, Only 65.9% of the time did these sampling methods share species among the top three collected. Therefore, determining the species responsible for risk of viral transmission to humans cannot necessarily be directly determined by CDC trap captures. The potential importance of *Ae. albopictus* in the southeastern and mid-Atlantic states emphasizes the limitations of CDC light trap samples for determining the species responsible for arboviral transmission to humans.

# RECOMMENDATIONS

The survey data collected in this study suggest that conditions are favorable for WNV activity at Gateway National Recreation Area and at Fire Island National Seashore. Potential for WNV activity was moderate at Minuteman National Historical Park, but was lower at the other parks sampled. Active surveillance programs are therefore appropriate at GATE and FIIS, and possibly at MIMA, while efforts at the other parks could be coordinated with local mosquito/WNV surveillance activities. In general, sites with high populations of enzootic vectors, *Cx. pipiens* or *Cx. restuans*, can develop epizootic WNV activity if reservoir competent bird species are abundant. If epizootic activity is detected, transmission to humans is most likely if potential bridge vectors are also common, especially in areas with dense human populations. If WNV activity is detected, surveillance can be coordinated with local mosquito abatement agencies to identify areas with risk of transmission to humans, and to implement appropriate management responses, if necessary.

**Acadia National Park, ME**

In this study, the most common mosquito species were *Cq. perturbans, Ae. punctor, Ae. cantator,* and *Ae. sollicitans.* Vector competence of *Ae. sollicitans* was moderate under lab conditions and competence of *Cq. perturbans* was low. Therefore, these species could potentially serve as bridge vectors, but with only low to moderate efficiency. *Cx. pipiens* and *Cx. restuans*, both of which are enzootic vectors of WNV, were present only in modest numbers. All of these species have been found infected with WNV, except *Ae. punctor*. If WNV activity is detected in the vicinity of ACAD, surveillance should focus on detecting areas with high populations of *Cx. restuans* or *Cx. pipiens* in proximity to populations of *Ae. sollicitans* or other vector species, especially near areas with dense human presence.

**Cape Cod National Seashore, MA**

*Cq. perturbans,* a potential bridge vector with low efficacy, was the most common species, with moderate numbers of *Cx. pipiens, Cx. restuans, Ae. canadensis* and *Ae. cantator*. All of these species have been found naturally infected with WNV. If WNV activity is detected in the vicinity of CACO, surveillance should focus on detecting areas of dense *Cx. restuans* or *Cx. pipiens* populations, especially near areas of dense human presence. It is not clear which species (if any) would be likely to act as a bridge vector on Cape Cod. Surveillance, and if necessary, management could be coordinated with local mosquito abatement staff.

**Delaware Water Gap National Recreation Area, NY/NJ/PA**

*Cx. pipiens, Cx. restuans, Ae. trivittatus, Cq. perturbans,* and *Ur. sapphirina*, all of which have naturally been found infected with WNV, were the most commonly trapped species in this study. Since *Cx. pipiens* and *Cx. restuans* are present, an enzootic cycle of WNV could potentially develop. However, it is not clear which species would be likely to act as bridge vectors at this site. Surveillance should be coordinated with the various local mosquito abatement authorities, and should be focused on detecting evidence of WNV activity at sites with large populations of both enzootic and bridge vector species, especially near areas of dense human presence.

**Fire Island National Seashore, NY**

The most common mosquito species were *Ae. sollicitans, Ae. vexans, Cx. salinarius,* and *Cx. pipiens*, all of which have naturally been found infected with WNV. *Cx. pipiens* is an important enzootic vector and *Ae. sollicitans, Ae. vexans,* and *Cx. salinarius* are potential bridge vectors of WNV. Therefore, conditions exist for WNV activity on Fire Island and an active surveillance program is indicated.

**Gateway National Recreation Area, NY/NJ**

Potential bridge vectors such as *Ae. vexans* and *Cx. salinarius* were abundant. *Cx. pipiens* and *Cx. restuans,* enzootic vectors of WNV, were also common. Additionally, a pool of *Cx. pipiens* collected from a trap set on August 15 tested positive for WNV. Therefore, data indicate that there is a risk for enzootic and epizootic cycles of WNV and an active surveillance program is indicated, especially in view of the dense human population adjacent to the park.

**Minute Man National Historic Park, MA**

*Ae. vexans, Cq. perturbans, Cx. pipiens,* and *Cx. restuans* were most abundant in this study. Thus, enzootic activity of WNV is possible. Epidemic activity is possible because *Ae. vexans* could potentially serve as a bridge vector. *Cq. perturbans*, on the other hand, is not an efficient bridge vector. Surveillance for WNV activity is appropriate (perhaps coordinated with local mosquito abatement personnel), especially at sites where *Cx. pipiens* (or *Cx. restuans*) and *Ae. vexans* are abundant.

**Roosevelt/Vanderbilt National Historic Site, NY**

*Ae. vexans*, a potential bridge vector of WNV, was common in this study. Enzootic vectors such as *Cx. pipiens* and *Cx. restuans* were also present in modest numbers. Therefore, data indicate that there is potential for an enzootic cycle of WNV to develop, but enzootic vectors were only modest in abundance and potential bridge vectors at this site display only moderate vector competence. If WNV activity is detected in the area, surveillance should focus on detecting sites with high densities of *Cx. pipiens* or *Cx. restuans*, in proximity to high activity of potential bridge vectors (especially *Ae. vexans*).

**Saratoga National Historic Park, NY**

In this study, *Cq. perturbans, Ae. trivittatus, Cx. pipiens,* and *Cx. restuans* were abundant. The potential development of an enzootic cycle of WNV is possible due to the presence of *Cx. pipiens* and *Cx. restuans*, but highly competent bridge vector species were not common. If WNV activity is detected in the area, surveillance should focus on detecting sites with dense populations of *Cx. pipiens* or *Cx. restuans* along with potential bridge vector species, especially near areas with abundant human activity.

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